

Determining the most suitable areas for artificial groundwater recharge via an integrated PROMETHEE II-AHP method in GIS environment (case study: Garabaygan Basin, Iran)

Hossein Nasiri · Ali Darvishi Boloorani · Hassan Ali Faraji Sabokbar ·
Hamid Reza Jafari · Mohamad Hamzeh · Yusef Rafii

Received: 17 August 2011 / Accepted: 23 February 2012 / Published online: 10 March 2012
© Springer Science+Business Media B.V. 2012

Abstract Flood spreading is a suitable strategy for controlling and benefiting from floods. Selecting suitable areas for flood spreading and directing the floodwater into permeable formations are amongst the most effective strategies in flood spreading projects. Having combined geographic information systems (GIS) and multi-criteria decision analysis approaches, the present study sought to locate the most suitable areas for flood spreading operation in the Garabaygan Basin of Iran. To this end, the data layers relating to the eight effective factors were prepared in GIS environment. This stage was followed by elimination of the exclusionary areas for flood spreading while determining the

potentially suitable ones. Having closely examined the potentially suitable areas using the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) II and analytic hierarchy process (AHP) methods, the land suitability map for flood spreading was produced. The PROMETHEE II and AHP were used for ranking all the alternatives and weighting the criteria involved, respectively. The results of the study showed that most suitable areas for the artificial groundwater recharge are located in Quaternary Q_g and Q^{gsc} geologic units and in geomorphological units of pediment and Alluvial fans with slopes not exceeding 3 %. Furthermore, significant correspondence between the produced map and the control areas, where the flood spreading projects were successfully performed, provided further evidence for the acceptable efficiency of the integrated PROMETHEE II-AHP method in locating suitable flood spreading areas.

H. Nasiri (✉)
Department of Human Geography,
Faculty of Geography, University of Tehran,
Tehran, Iran
e-mail: hossien.nasiri@gmail.com

H. Nasiri
e-mail: nasirih@ut.ac.ir

H. Nasiri · A. D. Boloorani · H. A. F. Sabokbar ·
M. Hamzeh
Department of GIS and RS,
Faculty of Geography, University of Tehran,
Tehran, Iran

H. R. Jafari · Y. Rafii
Department of Environmental Planning and Management,
Faculty of Environment, University of Tehran,
Tehran, Iran

Keywords Flood spreading · Water resource management · PROMETHEE II · AHP · GIS · Garabaygan Basin

Introduction

Groundwater is the single water resource in many regions of Iran. This is considered to be a major historical limitation in the social and economical

development of the country. Recent studies on the management of water resources in Iran have shown that out of the 430 billion m³ of the annual precipitation in the country, 20 % is lost during sudden floods which flow into the playas, lakes and seas (Foltz 2002; Mohammadnia and Kowsar 2003). The climate of the country is mainly classified as arid and semi-arid. In addition to the small amount and unbalanced distribution of precipitation (both spatially and temporally), high-intensity rainfalls which result in destructive floods bring about serious damages to downstream towns, roads, and agriculture, and sometimes even cause casualties (Hayati et al. 2006). Flood spreading on aquifers, thereby artificially recharging of the aquifers, is an efficient strategy for controlling floods and managing water shortage and water resources (ASCE 2001). While several groundwater recharge methods have been developed including the direct surface recharge, direct sub-surface recharge and indirect recharge techniques (Oakford 1985), the direct surface recharge method is one of the most cost-effective, simple and commonly used techniques employed for the artificial recharge of aquifers. The direct surface recharge method contains the surface spreading of floodwater and is helpful in areas with widely available land, highly permeable soils and a shallow unconfined aquifer (O'Hare et al. 1986).

Selecting optimal sites for flood spreading involves integrating several complicated parameters, which necessitates the use of geographic information systems (GIS) in combination with multi-criteria decision analysis (MCDA). Employing the MCDA and specialists expertise can lead to a more efficient use of GIS in site selection (Mehdipour 2007).

Studies on many of the issues relating to planning and managing water resources in the last two decades have been based on GIS analyses, without which the process would have been very costly, time-consuming and often followed by error.

GIS which is broadly used in decision making, managing, manipulating, processing, analysing, combining and overlaying information layers, is known as a useful tool in the planning and management of water resources (Kao and Lin 1996). Along with the GIS, remote sensing and the technology of satellite data processing with access to up-to-date and diverse information are broadly used in order to deal with management problems (Saraf and Choudhury 1998; Jha and Peiffer 2006). Accordingly, the mainpurpose of using remote sensing, GIS,

and multi-criteria decision making (MCDM) together in an integrated approach is to provide scientific evidence for the site selection processes (Ferdowsi 2005).

Many studies have found evidence for the efficiency of the combination of the satellite data, GIS and MCDM in locating the optimal zones for flood spreading (Krishnamurthy and Srinivas 1995; Krishnamurthy et al. 1996; Saraf and Choudhury 1998; Han 2003; Chowdhury et al. 2010). Using GIS and decision-making support systems, Ghayoumian et al. (2002, 2005, 2007), Zehtabian et al. (2001), Nouri (2003) and Alesheikh et al. (2008) have located suitable sites for the artificial recharge of aquifers. Kheirkhah Zarkesh (2005) has developed a decision support system for flood spreading site selection and a conceptual model of flood spreading schemes in the semi-arid areas of Iran.

Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is one of the relatively new MCDA techniques developed by Brans (1982). The method, presented for the first time at Laval University in Quebec (Brans 1982), was later expanded by Brans and Vincke (1985). The PROMETHEE is the outranking method and has theoretically and practically been employed in different fields including urban planning (Queiruga et al. 2008), energy (Opricovic and Tzeng 2007; Diakoulaki and Karangelis 2007), stock trading investment (Albadvi et al. 2007), transportation (Elevli and Demirci 2004) and agriculture (Kokot and Phuong 1999). The major strength of this method over the techniques such as SAW and analytic hierarchy process (AHP) is that PROMETHEE II takes into account the preference function of each criterion, determined by the decision makers. Therefore, in PROMETHEE II each criterion is evaluated on a different basis and it is possible to make better decisions. To the best of our knowledge, nonetheless, the PROMETHEE method has not been applied to the flood spreading site selection so far.

The groundwater-based agricultural activities in the Garabaygan Basin and the location of the region in the arid zone of Iran have highlighted the significance of water in this area. Considering these conditions, the present study aims to prevent the water loss in the region by determining suitable flood spreading sites and using the floodwater optimally. Having used the PROMETHEE II and AHP methods in combination with GIS, the suitable flood spreading areas were located. The AHP method was used to quantify the

subjective judgments of the evaluators as the weights of the criteria whereas the PROMETHEE method was employed to prioritise the alternatives based on the weights obtained from the AHP. The proposed PROMETHEE method can be useful for hydrologists in selecting suitable flood spreading sites and in the planning and management of groundwater resources.

Study area

The Garabaygan Basin (28°30' to 28°45' N and 53°45' to 54°01' E) is located in the south part of Fars province of Iran (Fig. 1). The mean elevation of the area is 1,476 m above mean sea level. According to the De Martonne climate classification, the area represents a dry climate type with the average annual rainfall of

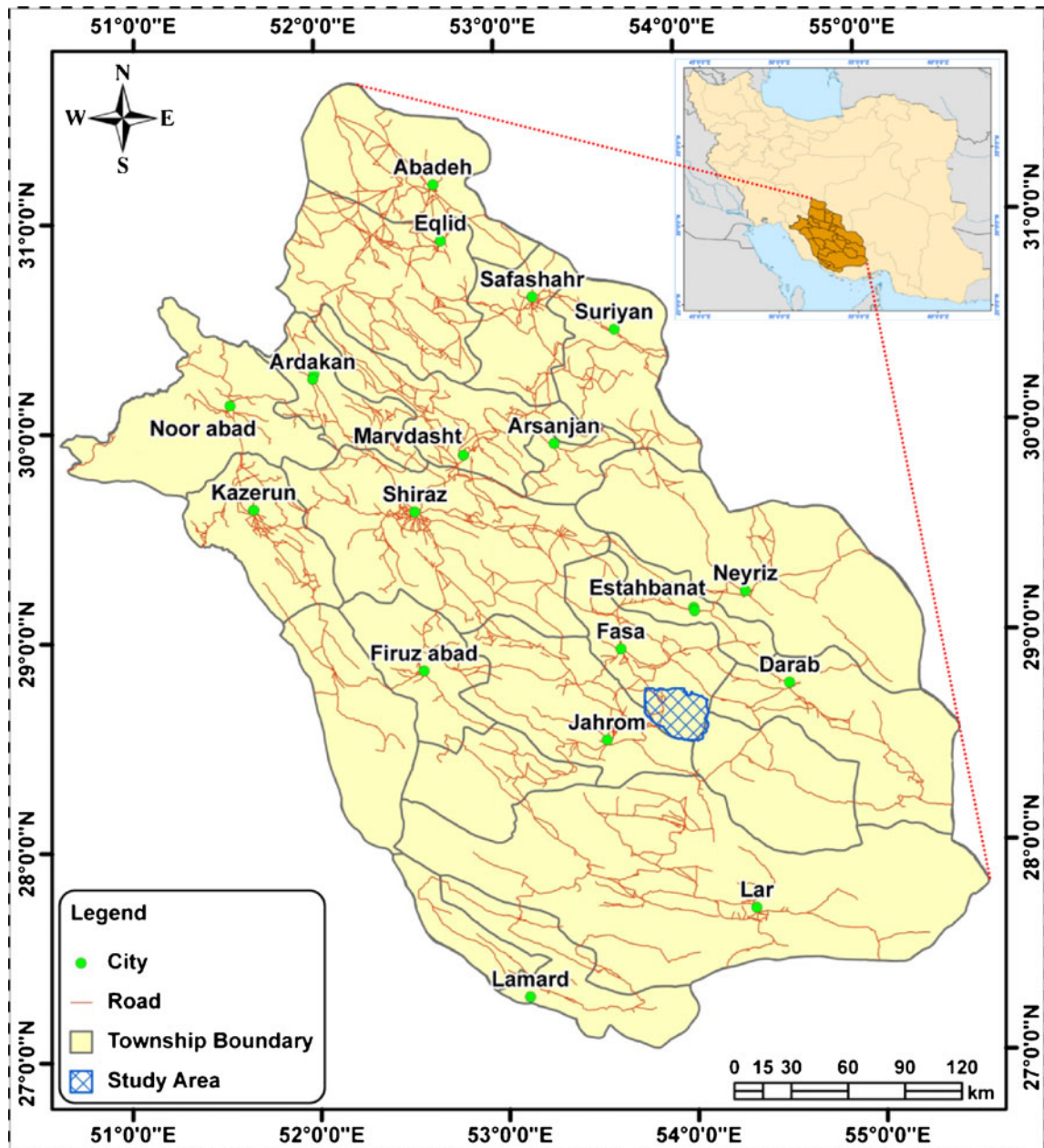


Fig. 1 Location of the Garabaygan Basin (in the Fars province of Iran)

259 mm, the average annual potential evaporation rate of 2,934 mm and the average annual temperature of 20.6°C. Garabaygan is an area located in the folded Zagros Mountains stretching like a folded belt from the northeast to the southwest of the country. In this area, only signs of the last two geological eras are found. The Mesozoic formation constitutes mountains and hill units and contains sandstone, limestone, claystone, siltstone and conglomerate. The Cenozoic formation is composed of alluvial deposits (with the average depth of 30 m), which in the forms of alluvial fans and pediments play the major role in the formation of the aquifers of the basin. The source of the water of the Garabaygan Basin is of both subsurface and surface types. Bishezard and Chahghuch seasonal rivers are the surface sources of water, with the former having a length of 28 km and being the major recharge source of the aquifers of the region and the latter having a less significant role.

Materials and methods

Determining the criteria for the flood spreading site selection

The potentially suitable areas for flood spreading have certain features; the identification of these features is contingent upon several factors. Considering the literature and the local conditions of the region and in order to build on the previous research, in the present study eight parameters namely slope, water quality, geology, alluvium thickness, land use, transmissivity and geomorphology, and the drainage density were identified as key criteria for the research purpose.

Slope Slope is one of the effective factors in the site selection of potentially suitable areas for flood spreading and groundwater recharge. National and international studies show that the areas with slopes lower than 5 % are suitable for flood spreading (Krishnamurthy et al. 1996; Ghermezcheshmeh et al. 2002).

Water quality The quality of groundwater demonstrates the amount of chemicals and biological impurities and is a major factor in specifying water for certain uses. In the present work, electrical conductivity (EC) has been employed as a parameter for assessing water quality index. EC and total dissolved solids

(TDS) were measured and their maps provided. Hence TDS and EC showed the same trend of change, only EC was used as the water quality index.

Geology Geology and the types of geological formations in the region have important roles in selecting flood spreading sites. Because of enjoying good permeability, transmissivity and high water storage capacity, limestone and coarse alluviums present good conditions for recharging aquifers. Coarse (sand and gravel) and pervious or karstic formations typically enjoy better hydraulic conductivities and aquifer transmissivity, and the regions with young alluvia are known to be suitable sites for flood spreading.

Alluvium thickness The thickness of alluvium is another major factor in flood spreading and groundwater recharge. Theoretically, the greater the thickness of alluvium, the larger the amount of groundwater storage. If all the parameters are appropriate except the alluvium thickness, flood spreading may cause saturation of the recharged layer (Hekmatpour et al. 2007).

Land use From the land use point of view, the Garabaygan Basin includes river bed, residential areas, rangeland and irrigated and dry farming. Undertaking artificial recharge projects is feasible in areas with an appropriate density of vegetation coverage because these regions not only recharge water into aquifers but also prevent the surface soil erosion. Poor rangelands, on the other hand, are not proper places for artificial recharge projects due to the increasing rate of soil erosion.

Aquifer transmissivity Aquifer transmissivity is one of the hydraulic properties, which represents the ability of the aquifer to transmit groundwater throughout its entire saturated thickness. This coefficient is indicated by different quantities but it typically ranges from 10 to 10,000 m²/day (Ghermezcheshmeh 2000). The formula for calculating aquifer transmissivity is:

$$T = K \times D \quad (1)$$

Where K is hydraulic conductivity and D is saturated layer thickness. In the present study, aquifer hydraulic conductivity was assessed through the pumping test, which is the best and the most precise method for the measurement of hydraulic conductivity

(Nakhaei 2009). Aquifer transmissivity in Garabaygan Basin varies as a function of the differences in the thickness of the saturated layer.

Geomorphology Geomorphological maps in places where no subsurface information could be obtained can be used as an appropriate criterion for flood spreading site selection (Ghermezcheshmeh 2000). Vast plains with moderate slopes, pediments and alluvial fans are considered the best locations for developing aquifer recharge projects (Ahmadi 2007). The area under study includes geomorphological units of floodplains, alluvial fans, pediments, rocky outcrops and hills. Floodplain, alluvial fans and pediment constitute 5.1, 3.3, 33.6 % of the area, respectively, while hills and rocky outcrops comprise the remaining 58 %.

Drainage density Drainage density is defined as the total length of channels per unit area. It is strongly related to maximum discharge in basin and calculated through the following formula:

$$\mu = \frac{\sum L_i}{A} \tag{2}$$

Where L is the length of each channel segment and A is the area of basin. There is an inverse relationship between drainage density and permeability. The less permeable the formation, the less the infiltration of rainfall (which conversely tends to be concentrated in surface runoff). This gives rise to a well-developed and fine drainage system. Accordingly, drainage density can be considered an indirect indicator of the suitability of an area for artificial groundwater recharge. Drainage density for all the micro-watersheds in the study area ranged from 0.6 to 2.3 km⁻².

Data collection and analysis

GIS datasets of the eight selected parameters were collected from different sources for the Garabaygan Basin. The land use and the geomorphological maps of the area were generated from the classification and interpretation of multispectral images of the Thematic Mapper sensor of Landsat Satellite at 30 m spatial resolution. To prepare the slope map of the area, the digital elevation model extracted from the 1:25,000 topographic map produced by the National Cartographic Centre was used. The 1:100,000 geologic map was obtained from the Geological Survey of Iran

(GSI). To produce the alluvium thickness map, data from 14 observational wells were used. In addition, seven extra-observational wells were utilised to validate the results of the spatial interpolation. In order to generate the water quality map, the electric conductivity data layer constructed from the data of 21 observational wells in a 10-year period was utilised.

The thematic maps were digitised and analysed using the GRASS GIS open source software. To prepare thematic maps, paper maps were first scanned; the scanned maps were georeferenced and finally digitised. In order to implement the proposed method, the data layers were converted to raster format with the uniform cell size of 30 by 30 m. Primary digital maps of geology, geomorphology and land use with qualitative structures were converted to raster datasets with respective quantitative values by use of Tables 1 and 2. For converting alluvium thickness, transmissivity and water quality point features into the raster forms, the ordinary kriging method was employed. The eight prepared maps as input data layers into proposed model are displayed in Fig 2.

Identification of exclusionary areas

The areas which are not suitable for flood spreading are called exclusionary areas. In the present study, based on the literature review and the local conditions of the area, four layers including slope, geomorphology, alluvium thickness and land use were taken into account to determine the exclusionary areas (Ghayoumian et al. 2007; Alesheikh et al. 2008). The slopes higher than 8 % in the slope layer, rocky outcrops in the geomorphological layer with thickness below 10 m in alluvium thickness layer, river bed and irrigated farming lands were considered as exclusionary areas for the flood spreading operation. Finally, the most suitable areas for flood spreading were identified using the integrated PROMETHEE II-AHP approach.

An overview of the PROMETHEE II method

The PROMETHEE II is used to provide a complete ranking on a finite set of feasible alternatives from the best to the worst. The basic principle of the technique is based on a pair-wise comparison of alternatives along each recognised criterion (Behzadian and Pirdashti 2009). This model is developed to solve multi-criteria problems and its major merit is that the information it requires is easily understandable

Table 1 Values given to geology map in order to converted to raster datasets with quantitative structure

Formation	Symbol	Lithology	Score
Quaternary sediments	Q _g	Pediment alluvial and proluvial deposits	7
	Q _b	Detrital fan containing piedmontcolluvial–proluvial deposits	7
	Q ^{gsc}	Alluvial–proluvial deposits contain gravel, silt and sand	7
	Q ^{scg}	Disalt alluvial deposits in young terraces, contain sand, silt, clay and minor gravel	5
	Q ^{e2}	Alluvial–proluvial deposits in young terraces	6
	Q ^{e1}	Piedmont alluvial–proluvial deposits and recent conglomerate in older terraces	3
Aghajari formation	MP1 _{aj2}	Mainly marls, marly sandstone and siltstone	1
Mishan formation	M _{m1-2}	Marl, sandstone and sandy limestone	2
Asmari-Jahrum formation	EOM	Limestone	3
Champeh member	M _{cp}	Limestone, dolomite and gypsum	2
Moul member	M _{m1}	Sandstone, fossiliferous limestone, marl and gypsum	6
Guri member	M _{gu}	Limestone and marlstone	3
Razak formation	M _{rz}	Silt, marls and silty limestone	4
Bakhtiary formation	PLQ _b	Conglomerate and sand	9
Lower part of Gachsaran formation	M _{gs-1}	Marls, marly limestone, gypsum and gypseous dolomite	4
Upper part of Gachsaran formation	M _{gs-2}	Gypsum, silty and marly limestone, marl and gypseous-bearing limestone	5
Lower part of Aghajari formation	PLa ₂	Calcareous sandstone, cherty sandstone and siltstone and micro-conglomerate	4

to analysts and decision makers (Pomerol and Barba-Romero 2000). According to Brans et al. (1986), the information needed to implement PROMETHEE II can be classified into two categories:

Weights or information between the criteria

The information between the criteria in fact shows weights representing the relative importance of each criterion. In PROMETHEE II, it is assumed that the decision maker is able to weight the criteria appropriately. Weights are non-negative numbers independent from the measurement units of the criteria. Weighting is a

Table 2 Values given to geomorphology and land use maps for being converted to raster datasets with quantitative structure

Criterion	Feature	Score
Geomorphology	Flood plains	10
	Alluvial fans	8
	Pediment	5
	Hills	2
	Rocky outcrops	0
Land use	Rangelands with sparse canopy cover	4
	Dry farming	1

difficult task and is highly affected by the knowledge and skillfulness of the decision maker. In the present study, the AHP method was used to weight the eight selected criteria.

Preference function or information within the criteria

A preference function translates the difference between two alternatives for a specific criterion into a preference degree between zero and one. For each criterion, only one preference function should be selected. Several preference functions can be defined; however, the six preference functions proposed by Brans and Vincke (1985)—linear, usual, Gaussian, U-shape, V-shape and level criterion—are the most commonly used ones. In each of the preference functions, at least two parameters out of the three following ones should be set (Figueira et al. 2005):

Indifference threshold (q) The largest deviation which is considered as negligible by the decision maker.

Preference threshold (p) The smallest deviation which is considered as sufficient to generate a full preference. According to the measurement scale, q and p are, respectively, small and large quantities.

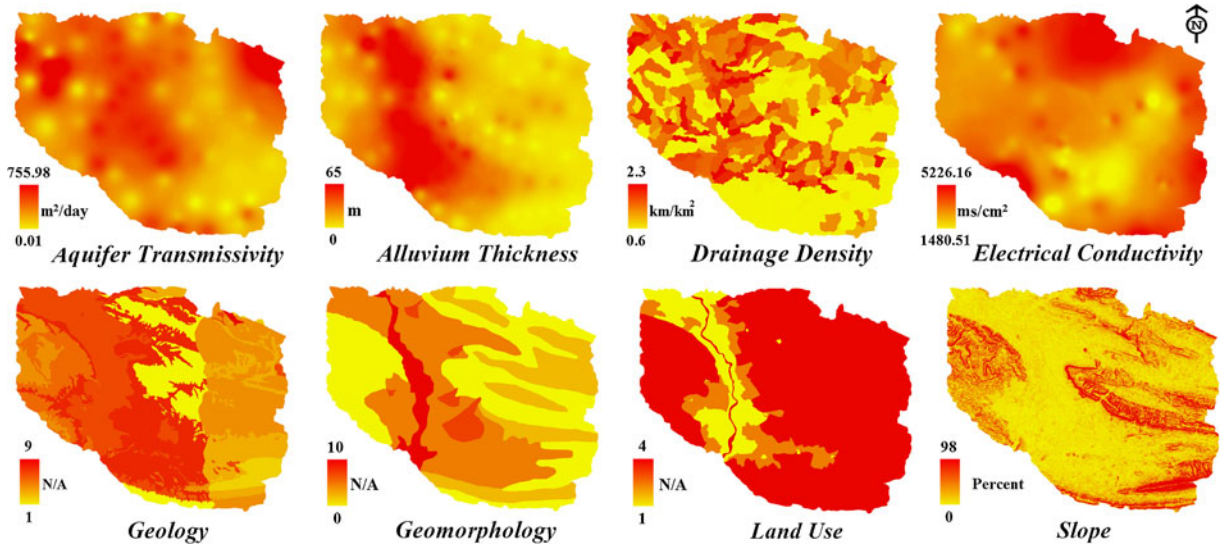


Fig. 2 Maps as input data layers into the proposed model

Gaussian threshold (s) The inflection point of the Gaussian preference function. It is recommended to determine first a q and a p and to fix s in between.

PROMETHEE II is implemented through the following steps (Behzadian and Pirdashti 2009).

Determination of deviations based on pair-wise comparisons;

$$d_j(a, b) = g_j(a) - g_j(b) \tag{3}$$

Where $d_j(a, b)$ denotes the difference between the evaluations of a and b on each criterion.

Application of the preference function;

$$P_j(a, b) = F_j[d_j(a, b)] \quad j = 1, \dots, k \tag{4}$$

Where $P_j(a, b)$ denotes the preference of alternative a with regard to alternative b on each criterion, as a function of $d_j(a, b)$.

Calculation of an overall or global preference index;

$$\forall a, b \in A, \quad \pi(a, b) = \sum_{j=1}^k P_j(a, b)w_j \tag{5}$$

Where $\pi(a, b)$ of a over b (from zero to one) is defined as the weighted sum $p(a, b)$ of for each criterion, and w_j is the weight associated with j th criterion.

Calculation of outranking flows and partial ranking;

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x) \tag{6}$$

And

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x, a) \tag{7}$$

Where $\phi^+(a)$ and $\phi^-(a)$ denote the positive outranking flow and the negative outranking flow for each alternative, respectively.

Calculation of net outranking flow and complete ranking;

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{8}$$

Where $\phi(a)$ denotes the net outranking flow for each alternative.

Assignment of the criteria weights via the AHP

In the present research, the AHP was used to determine the weights of the criteria. In fact, in the criteria weighting step the AHP and the PROMETHEE II methods are combined. The AHP was first proposed by the renowned mathematician Thomas L. Saaty (1980) as an appropriate decision-making approach to handle complex problems with numerous factors

Table 3 Pair-wise comparison matrix and normalised weights of the eight criteria extracted via the Expert Choice software

Criterion	Geomorphology	Geology	Drainage density	Slope	Aquifer transmissivity	Land use	Water quality	Alluvium thickness	Normalised weight
Geomorphology	1	1/2	1/2	1	2	3	2	2	0.136
Geology		1	2	2	2	3	2	3	0.225
Drainage density			1	2	2	2	2	3	0.184
Slope				1	3	2	3	3	0.159
Aquifer transmissivity					1	3	2	2	0.103
Land use						1	1/2	1/2	0.053
Water quality							1	1	0.074
Alluvium thickness								1	0.066
Total									1

involved. This process is used to assess the intangible qualitative criteria and the objective quantitative criteria (Badri 2001). To assign weights to the factors involved in the site selection through this method, the criteria are first organised in a hierarchical structure. Then a pair-wise comparison matrix is formed to make a pair-wise comparison between the criteria. In the pair-wise comparison, each of the criteria was assigned a weight ranging from 1 to 9. For this, the local conditions of the region, the relevant literature and the specialist expertise were considered and finally the relative weight of each criterion was determined using the eigenvector method in the environment of the Expert Choice software. Table 3 presents the pair-wise comparison matrix along with the weights of the eight criteria extracted via the software.

Determining necessary parameters for PROMETHEE II

In the present study some criteria (i.e., slope, groundwater and drainage density) have maximal effects

whereas some others (i.e., geomorphology, transmissivity, land use, geology and alluvium thickness) have minimal effects. On preference function type, following Brans et al.'s (1985) recommendation, Gaussian function was deployed for practical purposes especially for the continuing data. Hence, this function was selected for criteria containing continuity. For discrete data, the U-shape preference function was used. The AHP method was followed in order to weigh the criteria. In addition, the threshold values were determined for the selected preference function of each of the criteria (based on the difference between the minimum and maximum values). Table 4 presents the necessary parameters for utilising PROMETHEE II.

Results and discussion

The overall process of the flood spreading site selection has been schematically presented in Fig. 3. The collected data related to the eight parameters (slope,

Table 4 Necessary parameters for criteria to run PROMETHEE II

Criteria	Unit	Max/min	Preference function	<i>s</i>	<i>p</i>
Slope	Percent	Min	Gaussian	33.68	–
EC	µmhos/cm	Min	Gaussian	3027.67	–
Geology	–	Max	U-shape	–	3
Alluvium thickness	Meter	Max	Gaussian	53.26	–
Land use	–	Max	U-shape	–	1
Aquifer transmissivity	m ² /day	Max	Gaussian	544.93	–
Drainage density	km km ⁻²	Min	Gaussian	1.33	–
Geomorphology	–	Max	U-shape	–	3

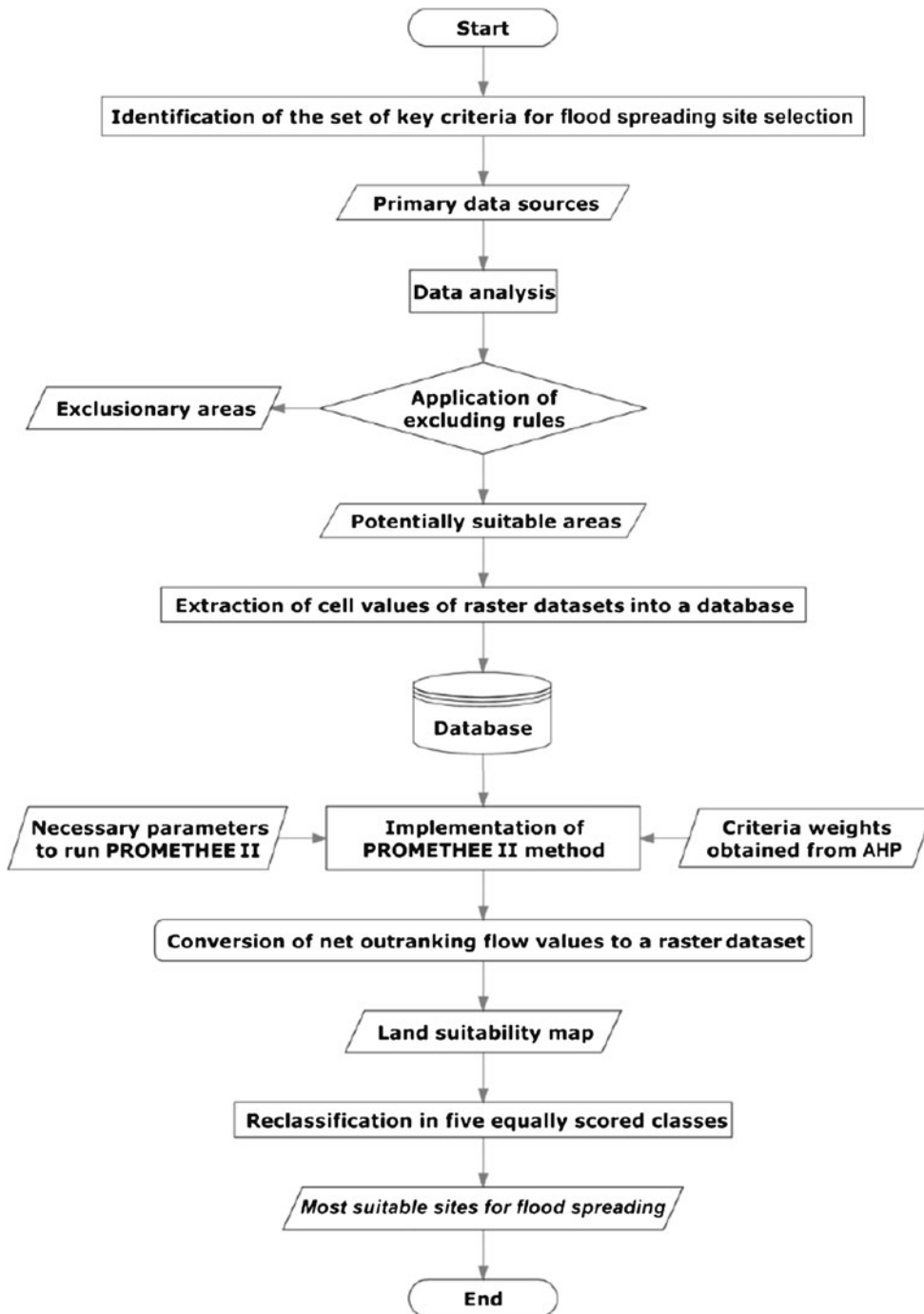


Fig. 3 Flowchart of proposed model to determine optimal sites for flood spreading

water quality, geology, alluvium thickness, land use, transmissivity, geomorphology and the drainage density) was analysed in the present work. Having collected the information layers according to the flowchart, the eight information layers were converted

into the raster format in the GIS environment in order to implement PROMETHEE II, and the preliminary spatial analyses were performed on them. The exclusionary areas were then removed according to the developed exclusionary map. Following this, the pixel

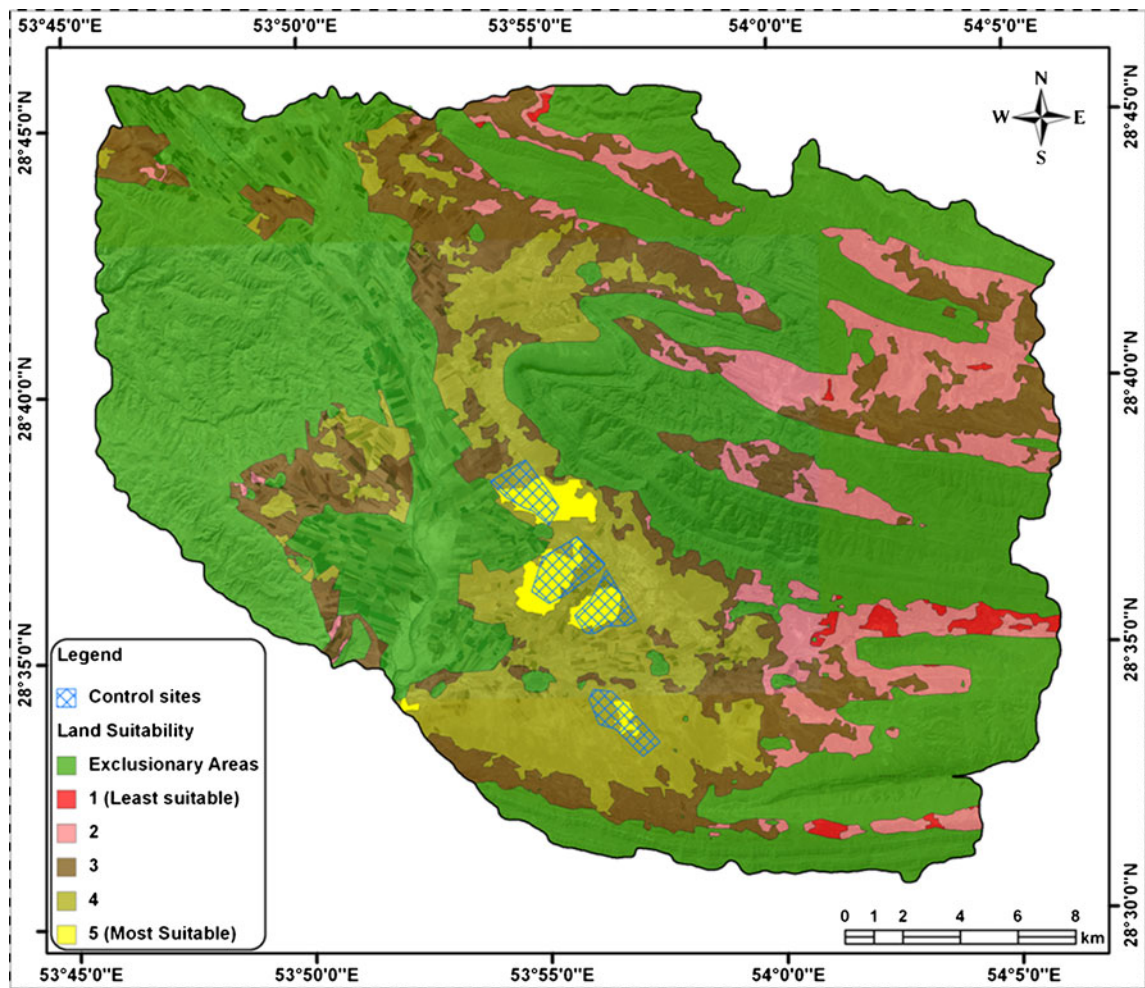


Fig. 4 Land suitability map resulting from the PROMETHEE II

values of the raster datasets related to the flood spreading site selection criteria were extracted and stored in eight separate fields in a database.

Whereas to implement PROMETHEE II method some software (e.g., Decision Lab and D-sight) can be utilised, in the present research project due to the large volume of the database the programming was done using MATLAB. After, the database was imported into the MATLAB, and the necessary information to run PROMETHEE II and the weights of the criterion (presented in Tables 3 and 4) were determined. The values of the net outranking flow were calculated for each alternative (each pixel of the raster dataset) using MATLAB programming. Finally, the values of the net outranking flow were converted to a raster dataset which was in fact the land suitability

map. The land suitability map was classified in five equally scored classes from the least suitable to the most suitable areas. The final land suitability map is presented in Fig. 4.

Table 5 The areas of the classes of land suitability map

Classes	Area (km ²)	Area (%)
Exclusionary areas	416.473	58.29
Most suitable	9.293	1.32
Moderately high suitable	105.311	14.7
Suitable	112.728	15.8
Moderately low suitable	65.825	9.21
Least suitable	4.845	0.67
Total	714.475	100

According to the final zoning map, the area belonging to “least suitable” class covers 4.85 km², “moderately low suitable” class 65.82 km², “moderately suitable” class 112.73 km², “suitable” class 105.31 km² and “most suitable” class 9.3 km² of the Garabaygan Basin. Table 5 presents the areas of these classes in square kilometre and per cent.

The results of the study show that the majority of the areas considered most suitable and suitable for flood spreading are located in alluvial and pediment geomorphological units and quaternary Q_g and Q^{gsc} geological units. This can be due to the location of the units on the margins of the streams and on the low slopes, the formation of these units from lime, silt, sand and gravel, as well as the good permeability of the units. In order to validate the results of the application of the integrated AHP-PROMETHEE II approach in GIS environment, the final suitability map of flood spreading was corresponded with the control areas where the flood spreading operation had been successfully tested; the results confirmed the acceptable efficiency of the proposed model.

Conclusions

Soil erosion and the flood-proneness of Iran have followed growing trends in recent decades. This can be mainly due to the inappropriate methods of using natural resources like water, soil and the green coverage of the watersheds. Planning to use floods not only can reduce their destructive effects but also provides new water resources for various uses. Flood spreading is one of the methods which set the ground for efficient utilisation of floods. In this study, the integrated MCDA-GIS approach was used in order to determine the suitable areas for flood spreading and artificial recharge of aquifers. To this purpose, the most important and effective factors in selecting suitable flood spreading areas were employed. The results of the study indicated the efficiency of the MCDA in flood spreading site selection and the effectiveness of PROMETHEE II in the rapid assessment of large areas. PROMETHEE II was used due to its simplicity and clarity. The present work proposes an innovative method for flood spreading site selection and can help policy and decision makers to approach water management issues with a deeper understanding of environmental factors. The proposed technique can set the

ground for using PROMETHEE II in other raster-based site selection research projects in the GIS environment.

References

- Ahmadi, H. (2007). *Applied geomorphology*. Tehran: University of Tehran Press.
- Albadvi, A., Chaharsooghi, S. K., & Esfahanipour, A. (2007). Decision making in stock trading: an application of PROMETHEE. *European Journal of Operational Research*, 177, 673–683.
- Alesheikh, A. A., Soltani, M. J., Nouri, N., & Khalilzadeh, M. (2008). Land assessment for flood spreading site selection using geospatial information system. *International Journal of Environmental Science and Technology*, 5(4), 455–462.
- ASCE STANDARD (2001). Environmental and Water Resources Institute, American Society of Civil Engineers. Standard guidelines for artificial recharge of groundwater, ASCE standards, EWRI/ASCE 34-01, p. 106.
- Badri, M. A. (2001). A combined AHP-GP model for quality controlsystems. *International Journal of Production Economics*, 72, 27–40.
- Behzadian, M., & Pirdashti, M. (2009). Selection of the best module design for ultrafiltration (UF) membrane in dairy industry: an application of AHP and PROMETHEE. *International Journal of Engineering*, 3(4), 126–142.
- Brans, J. P. (1982). Lingenierie de la decision. Elaboration instrumentsdaide a la decision. Methode PROMETHEE. In R. Nadeau & M. Landry (Eds.), *Laide a la Decision: Nature, Instrument s et Perspectives Davenir* (pp. 183–214). Quebec: Presses de Universite Laval.
- Brans, J. P., & Vincke, P. (1985). A preference ranking organisation method: the PROMETHEE method for MCDM. *Management Science*, 31(6), 647–656.
- Brans, J. P., Vincke, P., & Mareschal, B. (1986). How to select and how to rank projects: the PROMETHEE method. *European Journal of Operational Research*, 24(2), 228–238.
- Chowdhury, A., Jha, M. K., & Chowdary, V. M. (2010). Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS & GIS and MCDM techniques. *Environmental Earth Science*, 59, 1209–1222.
- Diakoulaki, D., & Karangelis, F. (2007). Multi-criteria decision analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews*, 11, 716–727.
- Elevli, B., & Demirci, A. (2004). Multicriteria choice of ore transport system for an underground mine: application of PROMETHEE methods. *Journal of the South African Institute of Mining and Metallurgy*, 104(5), 251–256.
- Ferdowsi, B. (2005). Application of decision support systems in the physical development of cities, case study: Sanandaj City. M.Sc. thesis, Faculty of Humanities, Tarbiat Modares University, Iran, p. 112.
- Figueira, J., Greco, S., & Ehrgott, M. (2005). *Multiple criteria decision analysis: state of the art surveys*. New York: Springer.

- Foltz, R. C. (2002). Iran's water crisis: cultural, political, and ethical dimensions. *Journal of Agricultural and Environmental Ethics*, 15(4), 357–380.
- Ghayoumian, J., Shoaiei, Z., Karimnejad, H.R., Ghermezcheshmeh, B., Abdi, P., 2002. Some examples of artificial recharge of aquifers by flood spreading in Iran. In: Van Rooy, J. L., Jerny, C.A. (Eds.), *Proceedings of the 9th Congress of the International Association for the Engineering Geology and the Environment*, Balkema, Rotterdam, pp. 1529–1537
- Ghayoumian, J., Ghermezcheshmeh, B., Feiznia, S., & Noroozi, A. A. (2005). Integrating GIS and DSS for identification of suitable areas for artificial recharge, case study Meimeh Basin, Isfahan, Iran. *Environmental Geology*, 47(4), 493–500.
- Ghayoumian, J., Mohseni Saravi, M., Feiznia, S., Nouri, B., & Malekian, A. (2007). Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran. *Journal of Asian Earth Sciences*, 30, 364–374.
- Ghermezcheshmeh, B. (2000). Assessment Quaternary deposits to determine suitable areas for flood spreading, case study: Northeast Esfahan. M.Sc. thesis, Faculty of Natural Resources, University of Tehran, Iran, p. 128.
- Ghermezcheshmeh, B., Ghayoumian, J., & Feiznia, S. (2002). Applying GIS and DSS to determine suitable areas for flood spreading in Meimeh Basin. *Journal of Science*, 3(2), 115–137 (In Persian).
- Han, Z. (2003). Groundwater resources protection and aquifer recovery in China. *Environmental Geology*, 44(1), 106–111.
- Hayati, D., Karami, E., & Slee, B. (2006). Combining qualitative and quantitative methods in the measurement of rural poverty: the case of Iran. *Social Indicators Research*, 75, 361–394.
- Hekmatpour, M., Feiznia, S., Ahmadi, H., & Khalilpour, A. (2007). Zonation of suitable areas for artificial groundwater recharge using GIS and DSS in Varamin Plain. *Journal of Environmental Studies*, 42, 1–8 (In Persian).
- Jha, M. K., & Peiffer, S. (2006). *Applications of remote sensing and GIS technologies in groundwater hydrology: past, present and future* (p. 201). Bayreuth: BayCEER.
- Kao, J. J., & Lin, H. Y. (1996). Multifactor spatial analysis for landfill siting. *Journal of Environmental Engineering*, 122(10), 902–908.
- Kheirkhah Zarkesh, M. (2005). Decision support system for floodwaterspreading site selection in Iran. Ph.D. thesis, International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands, p. 259.
- Kokot, S., & Phuong, T. D. (1999). Elemental content of Vietnamese rice. Part 2. Multivariate data analysis. *Analyst*, 124(4), 561–569.
- Krishnamurthy, J., & Srinivas, G. (1995). Role of geological and geomorphological factors in ground water exploration: a study using IRS LISS data. *International Journal of Remote Sensing*, 16(14), 2595–2618.
- Krishnamurthy, J., Kkumar, N. V., Jayaraman, V., & Manivel, M. (1996). An approach to demarcate ground water potential zones through remote sensing and geographic information system. *International Journal of Remote Sensing*, 17(10), 1867–1884.
- Mehdipour, F. (2007). A site selection model based on multi criteria decision making using GIS. *Survey Journal*, 3, 20–29. In Persian.
- Mohammadnia, M., & Kowsar, A. (2003). Clay translocation in artificial recharge of a groundwater system in the southern Zagros mountain, Iran. *Mountain Research and Development*, 23(1), 50–55.
- Nakhaei, M. (2009). *An introduction to hydrogeology*, Tehran, Iran. Aradketab Press.
- Nouri, B. (2003). Identification of suitable sites for groundwater artificial recharge using remote sensing and GIS in Gavbandi Watershed. M.Sc. thesis, Faculty of Natural Resources, Tehran University, Iran, p. 106.
- O'Hare, M. P., Fairchild, D. M., & Hajali, P. A. (1986). *Artificial recharge of groundwater* (p. 419). New York: Lewis.
- Oakford, E. T. (1985). Artificial recharge: methods, hydraulics, and monitoring. In T. Asano (Ed.), *Artificial recharge of groundwater* (p. 767). Boston: Butterworth.
- Opricovic, S., & Tzeng, G. H. (2007). Extended VIKOR method incomparison with outranking methods. *European Journal of Operational Research*, 178, 514–529.
- Pomeroy, J. C., & Barba-Romero, S. (2000). *Multi-criterion decisions in management: principles and practice*. Massachusetts: Kluwer.
- Queiruga, D., Walther, G., Gonza'lez-Benito, J., & Spengler, T. (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. *Waste Management*, 28(1), 181–190.
- Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw-Hill.
- Saraf, A. K., & Choudhury, P. R. (1998). Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *International Journal of Remote Sensing*, 19(10), 2595–2616.
- Zehtabian, G. R., Alavipanah, S. K., Hamedpanah, R. (2001). Determination of an appropriate area for flood water spreading by remote sensing data and GIS. In: *Proceedings of the International Conference on New Technology for a New Century*, Seoul, Korea, pp. 1–6.